Lasershot Makes Its Mark

ANYONE getting a hip replacement expects the implant to be certified and last a long time. The same goes for new and replacement parts in aircraft. The assumption is that critical parts—especially those used in applications where safety is paramount—are certified by the manufacturer and the government and are made to exact specifications. Lawrence Livermore and Metal Improvement Company, Inc., have developed a system that helps identify certified and other high-value parts.

The Lasershot Marking System imprints permanent, high-resolution identification marks that are difficult to counterfeit, readable by machine, and strengthen the part at the site of the mark, in contrast to other marking methods, which can actually weaken the part. “Before Lasershot, there was no way to permanently mark parts used in safety-critical applications without inducing the danger of fatigue and stress-crack corrosion,” notes Livermore physicist Lloyd Hackel, primary developer of the system.

From Hip Implants to Space Stations

The Lasershot Marking System has the potential to be of great use not only to makers of medical and aircraft components, but also to aerospace organizations such as the National Aeronautics and Space Administration (NASA). It is a prime candidate for imprinting safety-critical parts with the Air Transport Association 2000 Data Matrix, a high-data-intensity, two-dimensional, machine-readable symbol recently adopted by NASA. NASA plans to use this data matrix to identify and track the millions of parts used in the space program. Currently, the matrix is imprinted on the thousands of heat-resistant tiles on the Space Shuttle using a traditional marking technique. However, safety-critical metal parts are not marked at all because of the risk of marking-induced failure. The invention of the Lasershot Marking System means that NASA may soon be able to mark and track these important parts as well.

NASA has added Lasershot marking to its *Data Matrix Direct Part Marking Standard and Handbook* and included three samples imprinted with the mark in its Materials International Space Station Experiment, which was launched on the STS-105 in August. The sample parts were bolted onto the space station to face the slipstream solar wind. After one year, they will be retrieved and examined to evaluate how well they held up in the hostile space environment. NASA and the Department of Defense are also conducting ground, flight, and in-orbit tests of laser-peened marks to certify Lasershot’s use in current and future programs.

Other organizations—the Air Transport Association, the Electronic Industry Association, the Automotive Industry Action Group, and the Semiconductor Equipment

Livermore developers of the Lasershot Marking System are (left to right) Brent Dane, Lloyd Hackel, Hao-Lin Chen, John Halpin, and John Honig. The system was developed in partnership with James Daly, Fritz Harris, Laurie Lane, and James Harrison of Metal Improvement Company, Inc.

Manufacturers' Institute—have chosen the Data Matrix standard as the preferred one for parts marking, thereby extending the potential applications for the Lasershot system. Components that could be marked with this method include fan blades, disks, rotors, and integrated rotor assemblies as well as components in automobiles.

A mark created by the Lasershot system allows manufacturers and users to positively identify each individual part and trace each part from manufacture to retirement. In addition, Lasershot peen marking will be a valuable tool in combating counterfeit parts by providing a unique, permanent, and difficult-to-reproduce tracking symbol, one that also strengthens the part at the site. The mark contains fine detail nearly impossible to counterfeit, much like the watermark on modern currency. Part counterfeiting is a growing concern. According to government estimates, as much as $2 billion in unapproved parts are now sitting on the shelves of parts distributors, airlines, and repair stations.

A Chip off the Laser Peening Block

Peening—a technique common in metalworking—uses a ball-peen hammer or pneumatically shot small metal balls to pound a piece of metal into shape and strengthen it against fatigue failure. Replace the hammer or metal balls with a laser and the blow of metal on metal with the pressure wave of a laser light pulse on metal, and laser peening results. (See *S&TR*, March 2001, pp. 26–28.)

In the Lasershot peen-marking process, a layer of absorptive material is placed over the area to be peened, and a thin layer of water is flowed over the absorption layer. A high-intensity laser with an energy density (fluence) of about 100 joules per square centimeter illuminates and ablates material from the absorption layer, creating an intense pressure pulse that is initially confined by the water. The absorption layer protects the part surface from material removal or melting. The pressure pulse creates a shock wave that strains the surface in a two-dimensional pattern that mirrors the laser's intensity profile. By creating the desired pattern upstream in the light and then imaging this pattern onto the metal, a complete mark can be made with a single laser pulse.

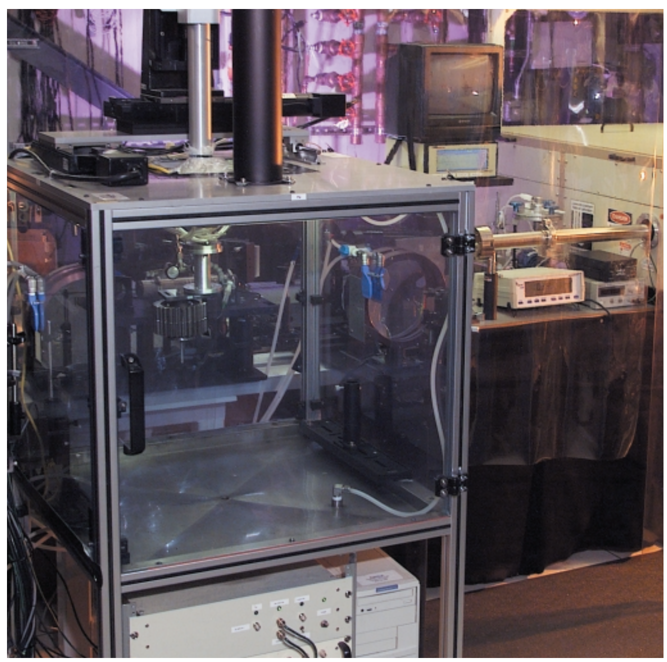
"The laser system projects the pattern on the part in much the same way that a slide projector creates an image on a screen," explains Hackel. "A slide projector without a slide in place projects a light field of uniform intensity on the screen. No image or pattern appears. When a slide is inserted between the projector bulb and lens, the light and dark areas of the slide provide an intensity profile pattern that is imaged onto the screen. With the Lasershot system, we use a laser and a special telescopic system to image the pattern of a mark onto the metal part. The laser fires, and that entire mark is printed on the part in a single pulse."

This single-pulse technique is well suited for high-volume marking applications. For low-volume use, a smaller system—the multiple-shot matrix marking system—builds up a two-dimensional mark using multiple laser pulses.

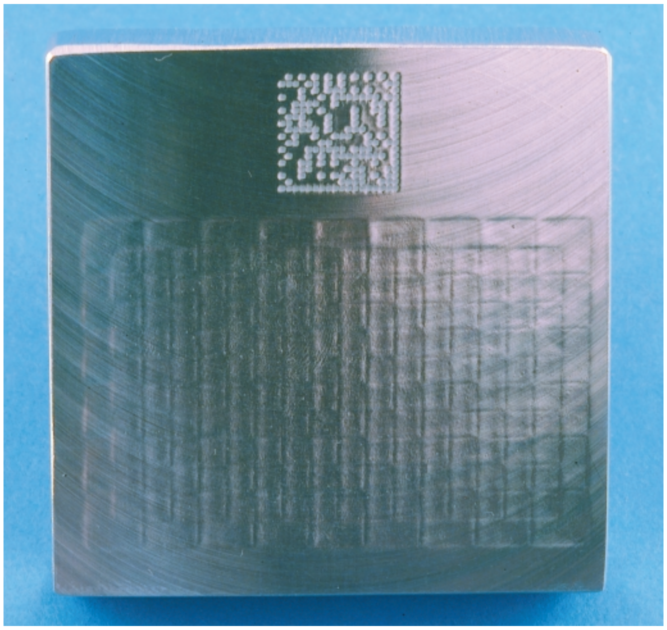
Technology Breakthroughs Make It Possible

The Lasershot technique was made possible by a patented breakthrough in laser technology developed at Livermore involving a neodymium-doped glass laser and a wavefront correction technology, called phase conjugation. "We can now build laser systems that operate up to six pulses per second, with output energy of greater than 25 joules," says Hackel. "This means we can peen-mark six data matrices per second, using the single-shot pattern marking technique." The phase conjugation provides a high-quality beam that has high, long-term pointing stability for the high repetition rates needed for the smaller multiple-shot marking system. As a result, the Lasershot system can mark parts at a rate comparable to or exceeding that of conventional marking methods.

The other key to the system is a specially designed and patented telescopic delivery system, which precisely relays



A Lasershot peen-marking station. The Lasershot Marking System (shown in action in the background of p. 8) uses laser pulses to safely and permanently impress identification markings on metal components without weakening them. The system is thus ideal for marking parts used in situations where safety is critical—from hip-joint replacements to commercial airliner components.



A 10- by 10-character identification mark—approximately 0.3 centimeter on a side—imprinted into an aviation-grade aluminum alloy using the Lasershot Marking System. Unlike other marking methods, Lasershot increases the marked area's resistance to fatigue and corrosion failure, and the resulting high-resolution mark is difficult to counterfeit.

the image onto the part surface. "This beam delivery is critical for accurately replicating a two-dimensional marking pattern," notes Hackel. "The resulting mark has uniquely embossed fine detail, making it nearly counterfeit-proof."

Mark Is Stronger, More Durable

Although other techniques are available for imprinting identification marks on metal parts, none measures up to the Lasershot method. The primary techniques are laser etching, pin stamping, and ink-jet printing. Laser etching systems work by focusing energy directly onto the surface to be marked and etching the surface with heat. The heat generated actually alters the part's surface, even vaporizing the surface in some cases. Although this technique has good permanence and generates a clear mark, it modifies the material. In steel, for instance, the high temperature causes carbon to precipitate out in the area hit by the laser beam, ultimately degrading the part's strength. The material modification and strength degradation can lead to fatigue or stress-corrosion crack failures. In a scanning electron micrograph study of 10 hip replacement implants that had failed much earlier than they should have, 5 of the 10 showed fatigue fractures that began in the characters that had been laser-etched on the implant surfaces. "These failures could have been prevented by the Lasershot method," notes Hackel.

In pin stamping, a conical stylus impacts the surface, with the size of the mark controlled by how deeply the stylus indents the metal. Like peening with a conventional ball-peen hammer, pin stamping may leave some residual compressive stress in the part, which would provide some protection against fatigue and mechanical stress. However, this method also roughens the surface and concentrates the stress at the bottom of the sharp indentations. In addition, pin stamping can distort small or thin parts.

Although marking using the ink-jet technique does not affect the surface material, the markings are not necessarily permanent. The permanence of the mark depends on the chemical interaction of ink and part as well as on the environment in which the part is used.

Sandblasting, machining or engraving, chemical etching, and welding also degrade strength and shorten the fatigue lifetime of metals. "Other techniques can cast symbols on parts during manufacturing," notes Hackel. "However, they only work for larger parts and don't address the need to mark parts already manufactured or those produced by noncasting methods such as forging and machining."

Unlike laser etching, Lasershot removes no material, and the marked surface remains chemically unaltered. Unlike pin-stamped marks, Lasershot does not roughen the surface. Plus the compressive layer from laser peening extends as deep as 1 millimeter into the metal, adding strength to this local area.

Mark the Future for Lasershot

The Lasershot Marking System allows manufacturers for the first time to safely and permanently mark and label metal parts used in situations where failure means big trouble. Donald L. Roxby, director of the Symbol Research Center, an international leader in the development of advanced symbology solutions for industrial, materials handling, and manufacturing environments, notes in a recent letter to Hackel, "Our organization was elated when we became aware of your work related to lasershot peening. The lasershot peening process provides the marking fidelity required to apply dense symbols to small parts without injecting risk. The process makes it possible to identify internal engine components such as aircraft turbine blades and a host of other difficult marking applications."

The R&D 100 Award judges voted their agreement. Lasershot is poised to make its mark in the world of safety-critical parts manufacturing.

—Ann Parker

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For further information contact Lloyd Hackel (925) 422-9009 (hackel1@llnl.gov).